Neutron induced reaction measurements at GELINA and at the High Flux Reactor of the ILL in Grenoble

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Collaboration:

UNIVERSITEIT GENT

NEUTRONS FOR SCIENCE® Institut Laue-Langevin

SCK•CEN STUDIECENTRUM VOOR KERNENERGIE CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

irmm Institute for Reference Materials and Measurements

Introduction

Neutron induced reaction measurements

1 at the High Flux Reactor
Institute Laue-Langevin (ILL), Grenoble (France)

$^{249}Cf(n,f)$ — ternary fission measurements

2 at GELINA
Institute for Reference Materials and Measurements (IRMM), Geel (Belgium)

$^{245}Cm(n,f)$
$^{41}Ca(n,\alpha)$
— cross section measurements

Ternary fission measurements

ILL Grenoble

High Flux Reactor ternary fission

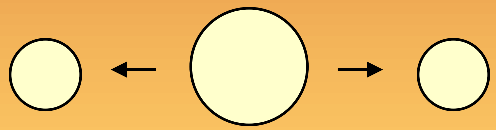
Institute Laue-Langevin (ILL)

- High Flux Reactor: above 10^9 n/cm^2/s
- PF1b neutron guide
- 76 m length

High Flux Reactor — ternary fission

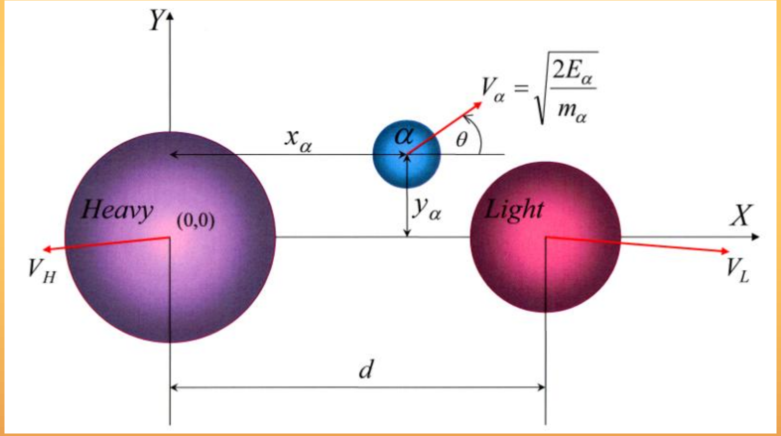
- Fission: a binary process

  Two heavy fragments are formed when the fissioning nucleus splits



- Ternary fission:
  three particles are formed

  discovered in 1946



Light Charged Particle (LCP) accompanied fission

$1 \leq Z \leq 10$ — 2 to 4 times every thousand fission events

Why do we measure ternary particles?

- Applied research

  Important source of helium and tritium gas production
  in nuclear reactors and used fuel elements

  Accurate data requested by nuclear industry and safety specialists

- Fundamental research

  Improving our understanding of the ternary particle emission

  Ternary particles are emitted in space and time close to the scission point
  → information on the fission process itself

Aim of this work:

- Enlarge the available databases → yields and energy distributions
- Search for systematics in these parameters
- Examine influence of the excitation energy

Emission probabilities or yields

- most common: ternary alpha particles
  - → Long Range Alpha (LRA) particles (↔ radioactive alpha decay)
- tritons (t) and ^{6}He particles

Energy distributions

- Gaussian in shape
- Average energy and Full Width at Half Maximum (FWHM)
- Difficult to measure low energy part
  - → Threshold due to thickness of detector and protecting foils

Influence excitation energy on emission probabilities

Comparing for the same compound nucleus:

- Spontaneous fission (SF)

  E_{exc} = 0 MeV

- Neutron induced fission (n_{th},f)

  E_{exc} = neutron binding energy ≈ 6-7 MeV

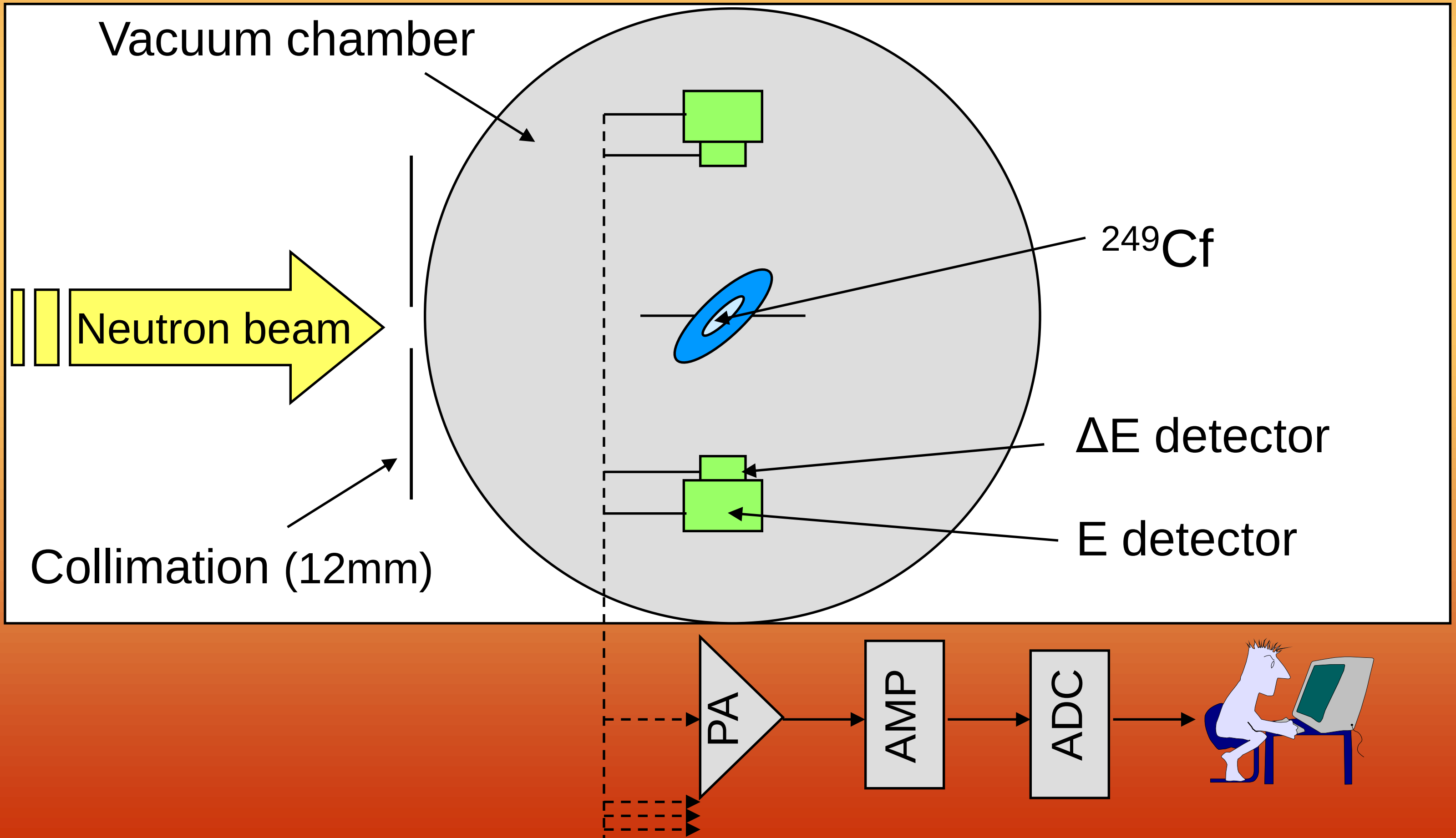
New results on the isotope ^{249}Cf(n,f)

(sample 0.88 MBq, almost 100% ^{249}Cf,
prepared at the Lawrence Berkeley National Laboratory)

Detection system

Need for particle identification

→ ΔE-E telescope detectors



High Flux Reactor — ternary fission

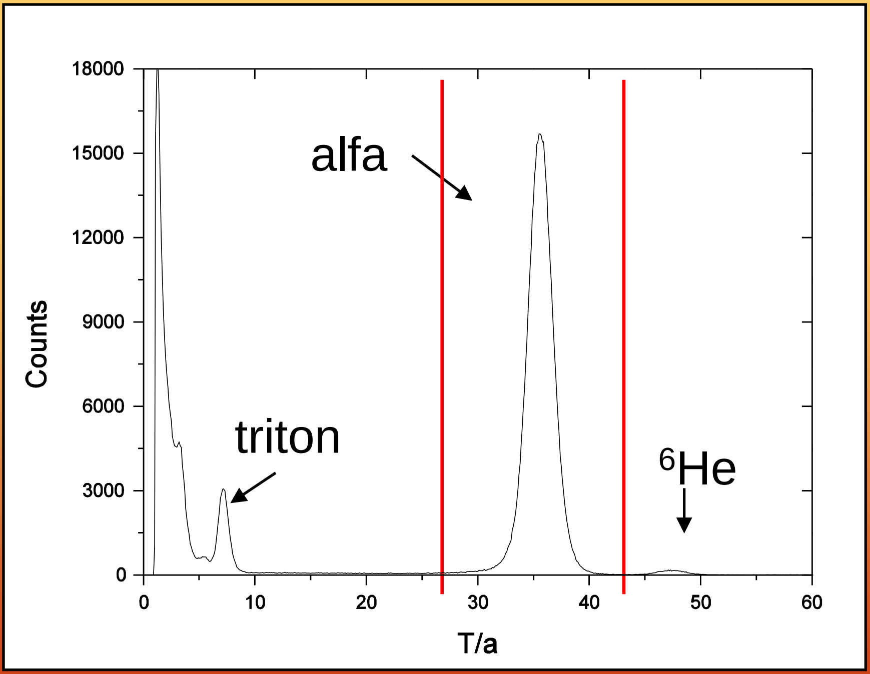
Particle identification

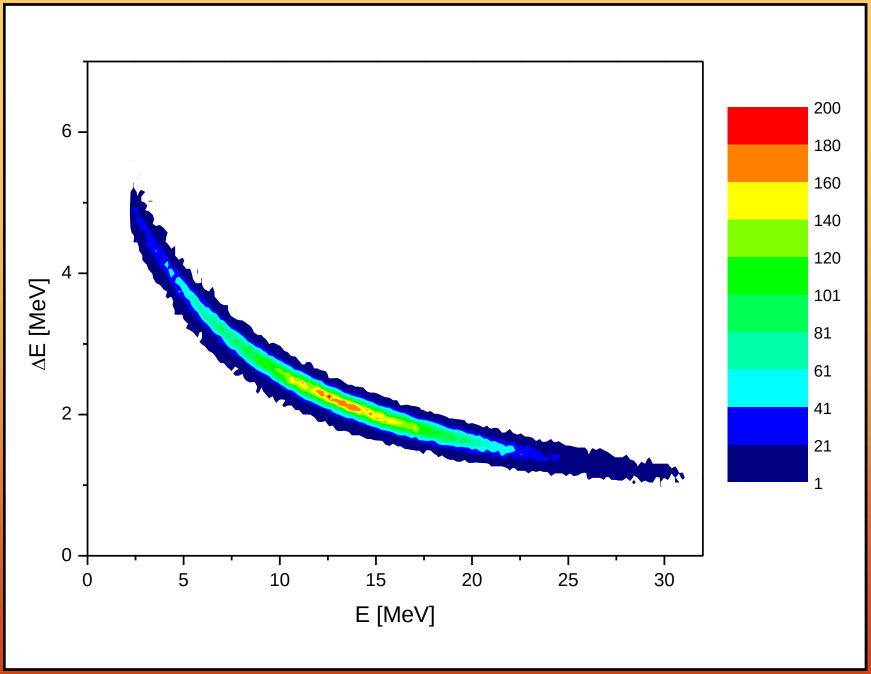
(Goulding)

Based on the difference in energy loss of different particles in the same material

$$T/a = (E + \Delta E)^{1.73} - E^{1.73}$$

(T = thickness of ΔE detector, a particle and material specific constant)

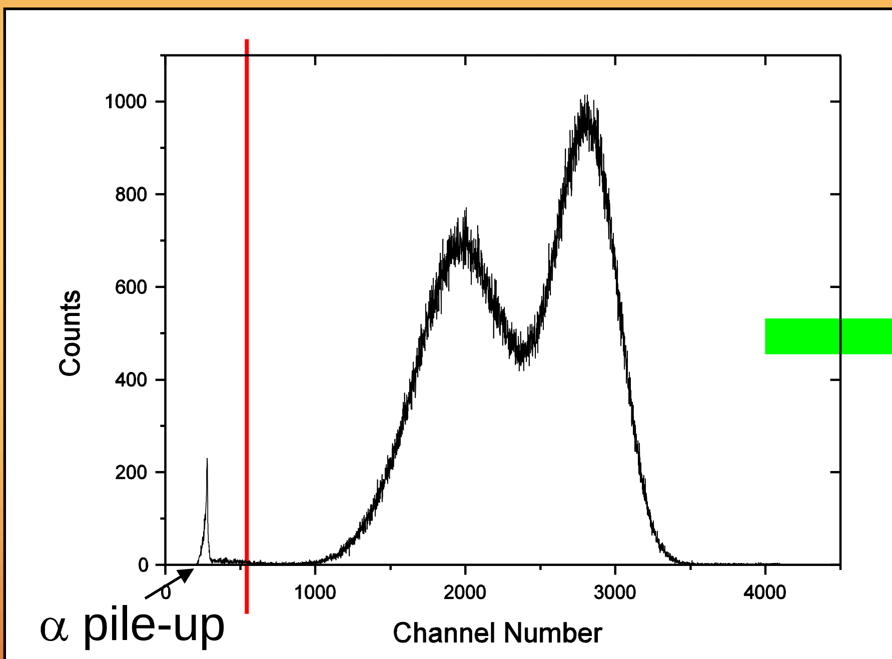


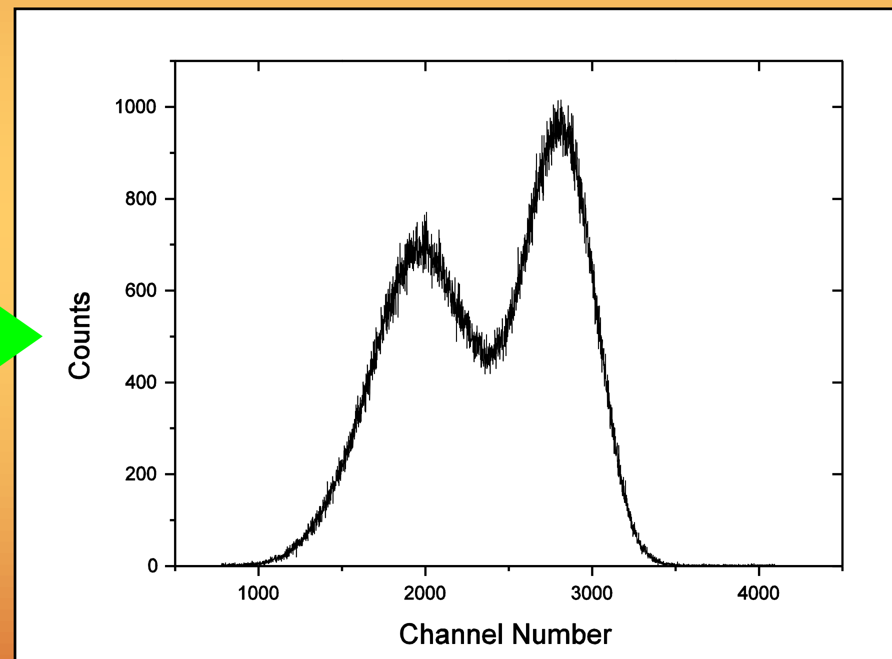


High Flux Reactor — ternary fission

Binary Fission (B)

First step: measurement only with E detector, ΔE replaced by a dummy, detection of the fission fragments



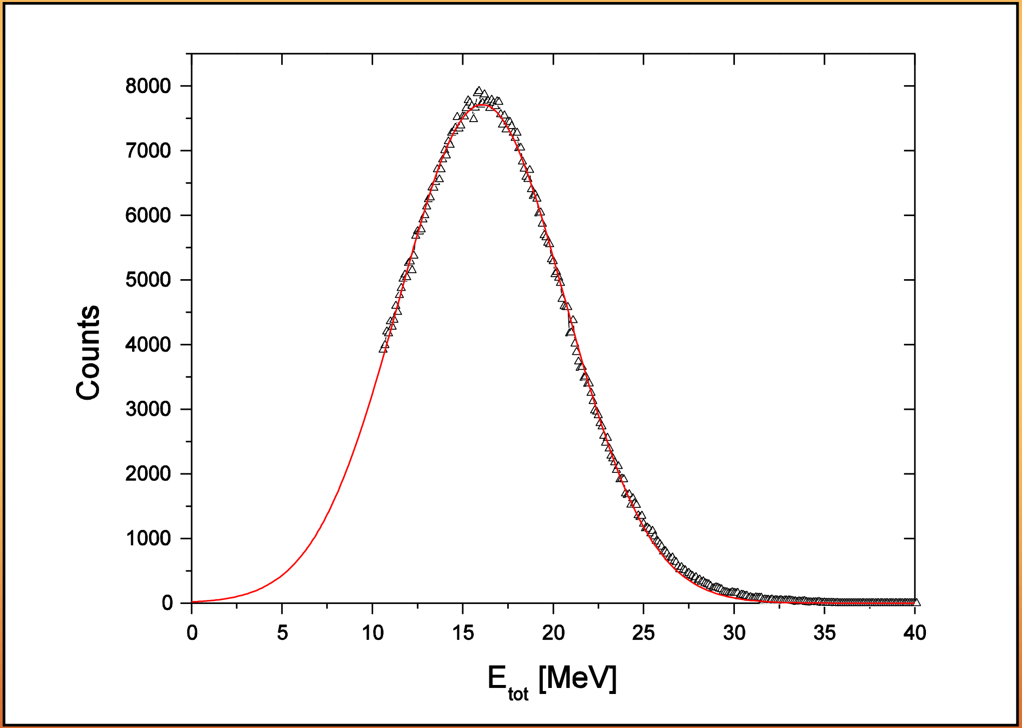


1029.81 3.07 B/s

High Flux Reactor ternary fission

Second step: measurement with ΔE-E detector,
detection of the ternary particles

LRA-particles: Gaussian fit from 12.5 MeV



E = 16.07   0.11 MeV

FWHM = 10.84   0.14 MeV

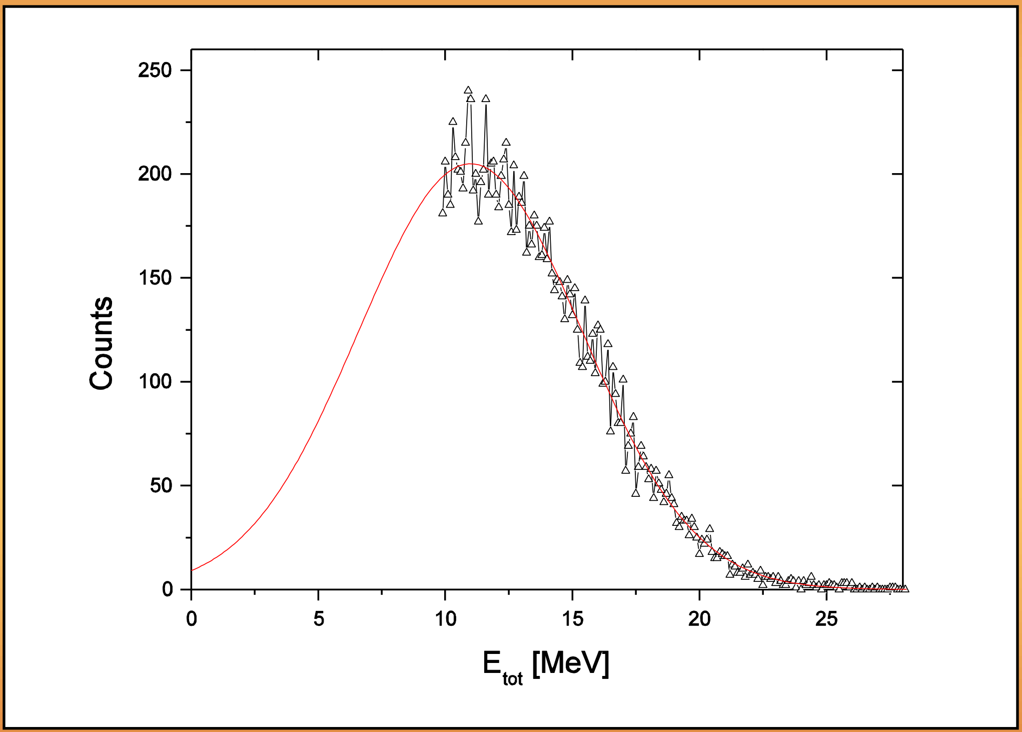
Area = 890515   8556

2.82   0.08 LRA/s

Combining both results: LRA/B = (2.74   0.08)x10^{-3}

High Flux Reactor ternary fission

^{6}He-particles: Gaussian fit from 9.9 MeV



E = 10.99   0.32 MeV

FWHM = 10.35   0.60 MeV

Area = 22588   2017

0.068   0.006 ^{6}He/s

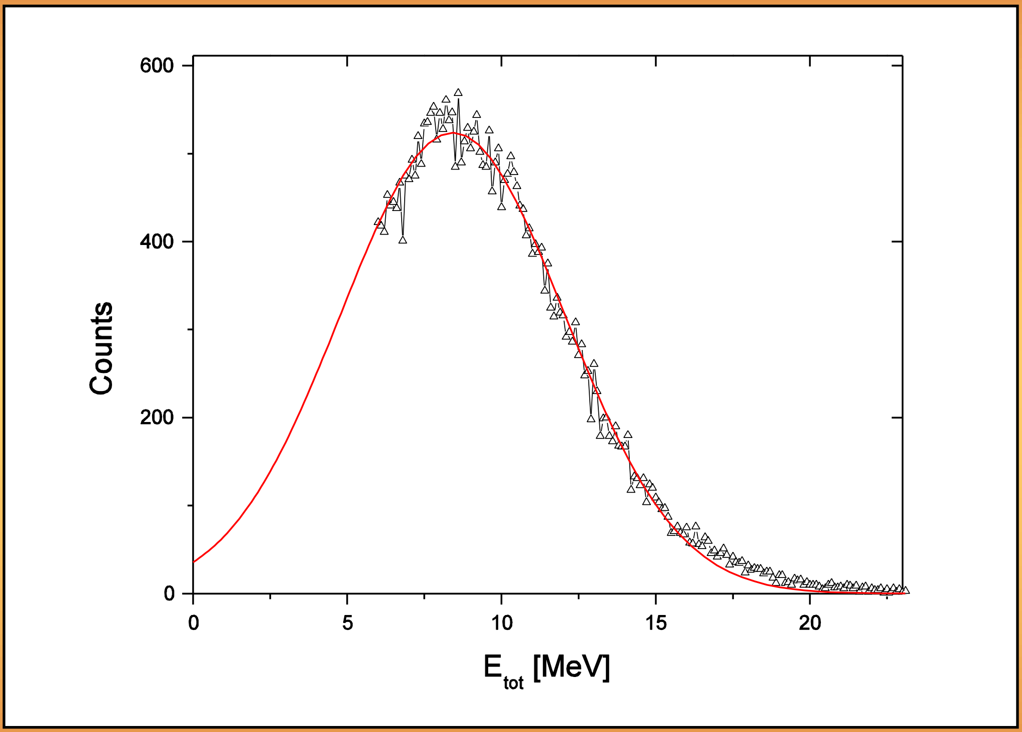
Combining the results:

^{6}He/LRA = (2.54   0.23)%

^{6}He/B = (6.99   0.66)x10^{-5}

High Flux Reactor   ternary fission

Tritons t: Gaussian fit from 6 MeV



E = 8.42   0.27 MeV

FWHM = 8.55   0.43 MeV

Area = 47654   3245

correction background contribution

0.230   0.018 t/s

Combining the results:

t/LRA = (7.68   0.61)%

t/B = (2.10   0.18)x10^{-5}

t and α emission studied under the same experimental conditions
(C. Wagemans et al.)

Neutron induced fission

^{229}Th, ^{233,235}U, ^{237}Np, ^{239,241}Pu, ^{241,243}Am, ^{243,245,247}Cm, ^{249,251}Cf

Spontaneous fission

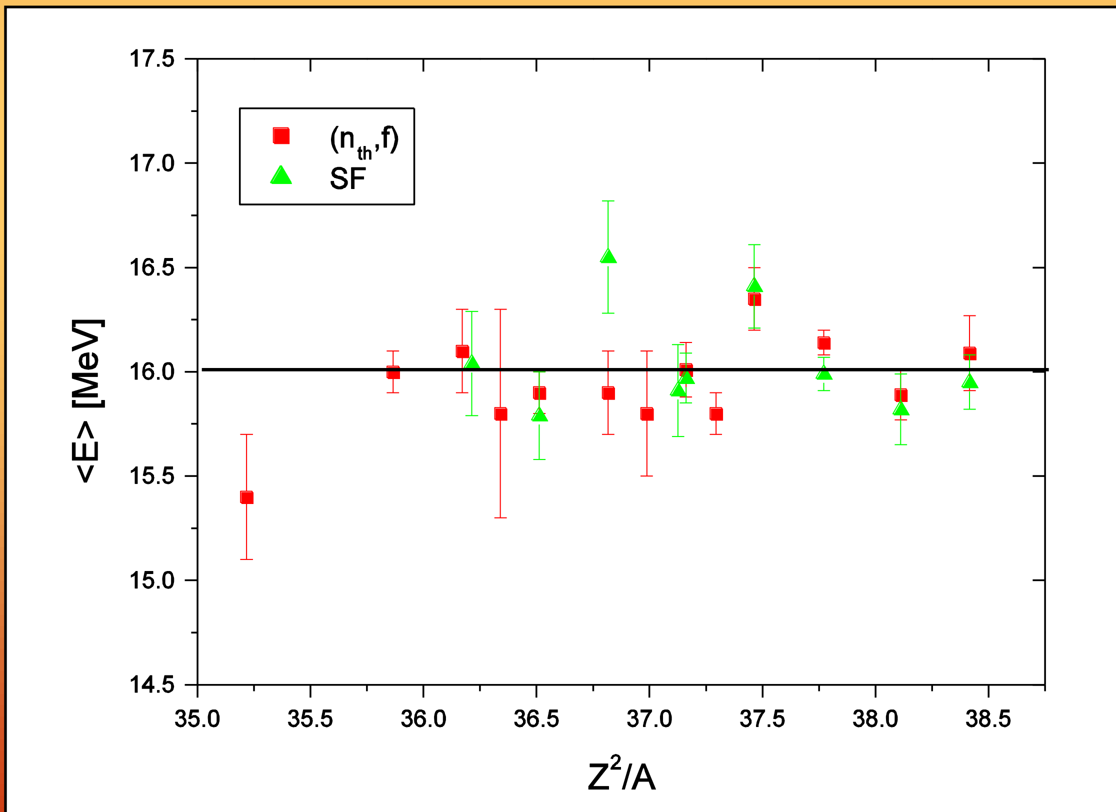
^{238,240,242,244}Pu, ^{244,246,248}Cm, ^{250,252}Cf

High Flux Reactor ternary fission

Average LRA energy <E>

(as a function of the fissility parameter Z^2/A of the compound nucleus)

➡ remains practically constant for all fissioning systems



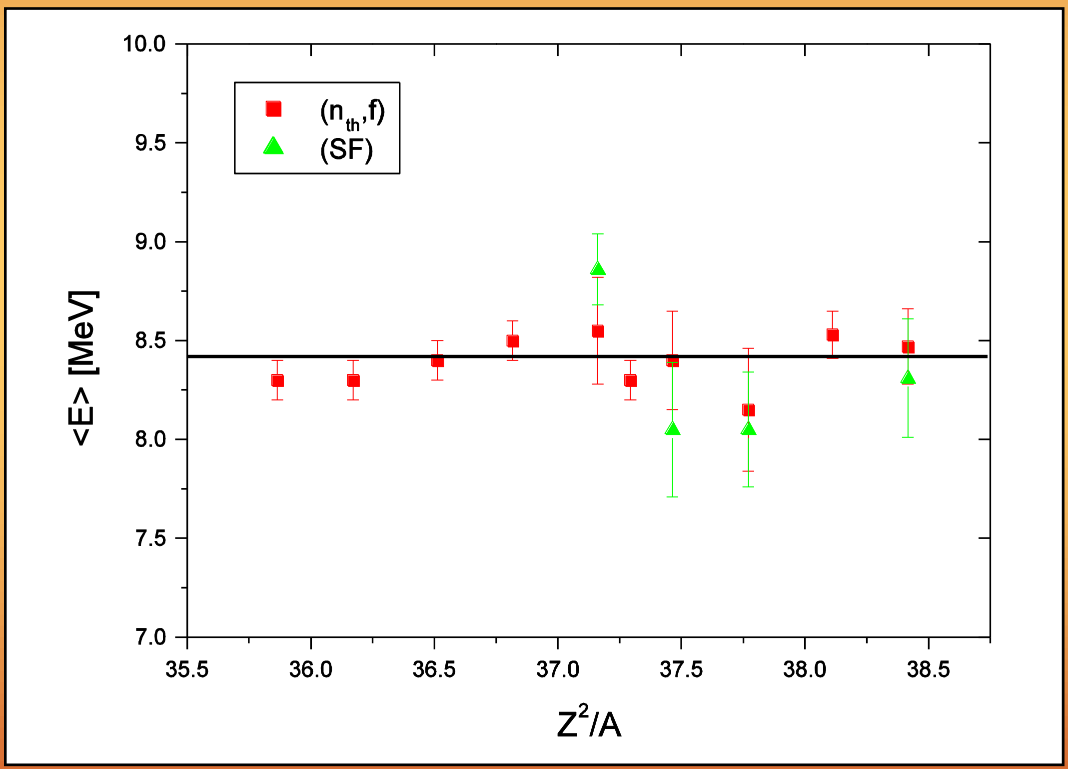
<E> = 16.0   0.1 MeV

High Flux Reactor ternary fission

Average triton energy <E>

(as a function of the fissility parameter Z^2/A)

➡ remains practically constant for all fissioning systems



<E> = 8.4   0.1 MeV

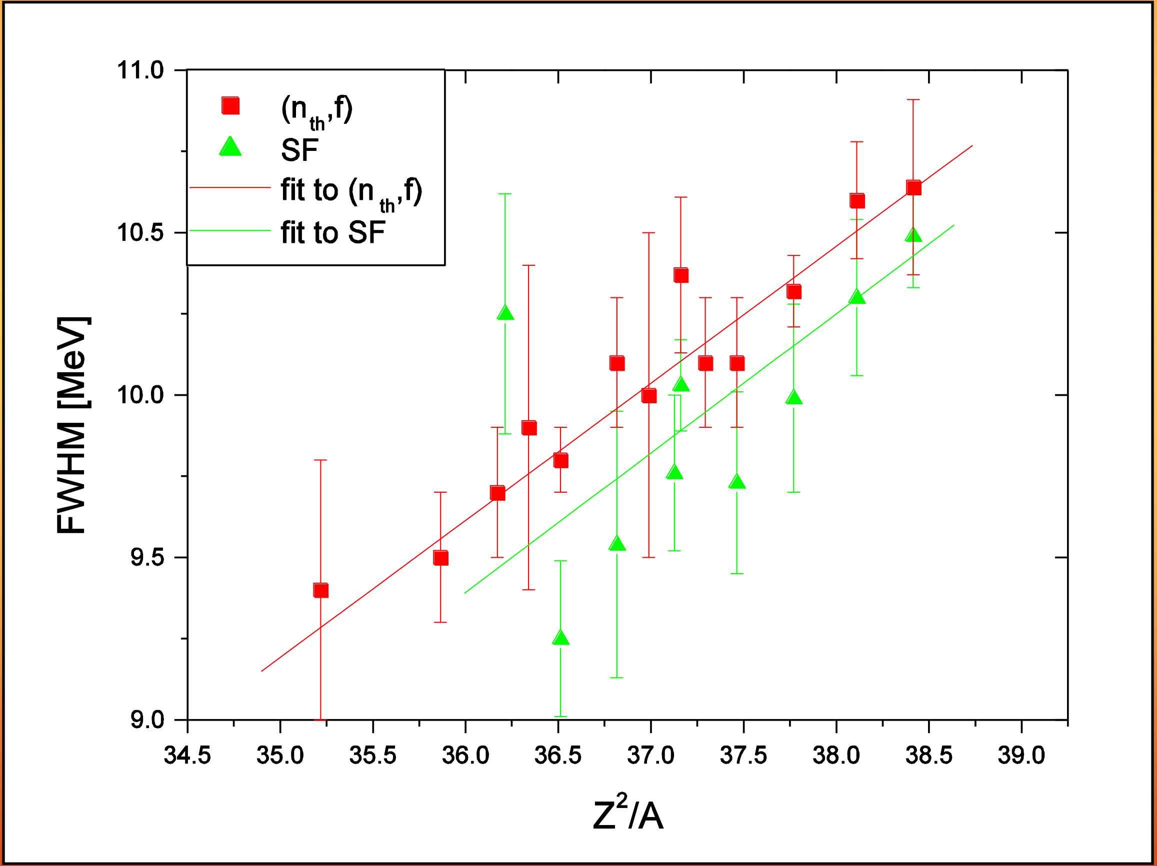
Average ^{6}He energy <E>

<E> = 10.8   0.2 MeV

High Flux Reactor ternary fission

FWHM LRA

(as a function of the fissility parameter Z^2/A)



➡ Increases with increasing Z^2/A

(explained by trajectory calculations)

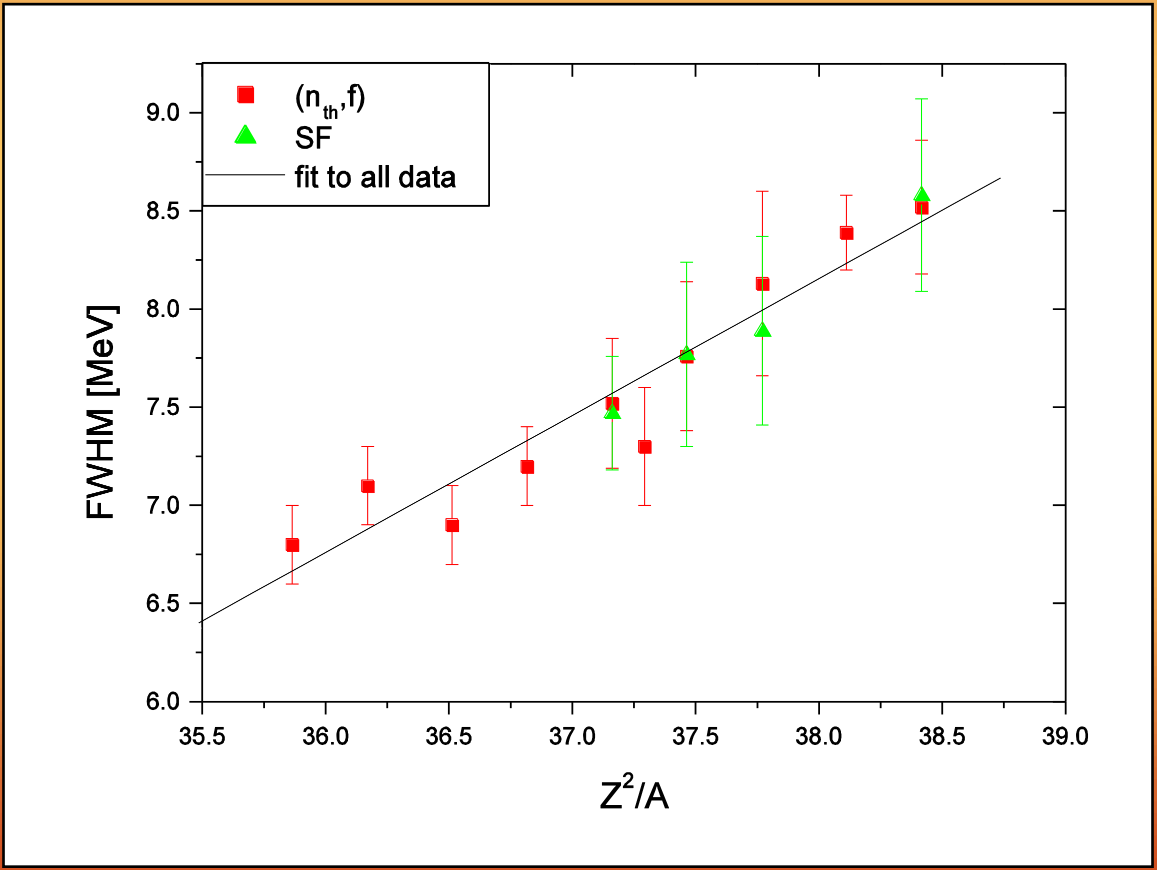
!

FWHM(SF) < FWHM(n_{th},f)
difference about 0.3 MeV
(excitation energy broadens)

High Flux Reactor ternary fission

FWHM triton

(as a function of the fissility parameter Z^2/A)



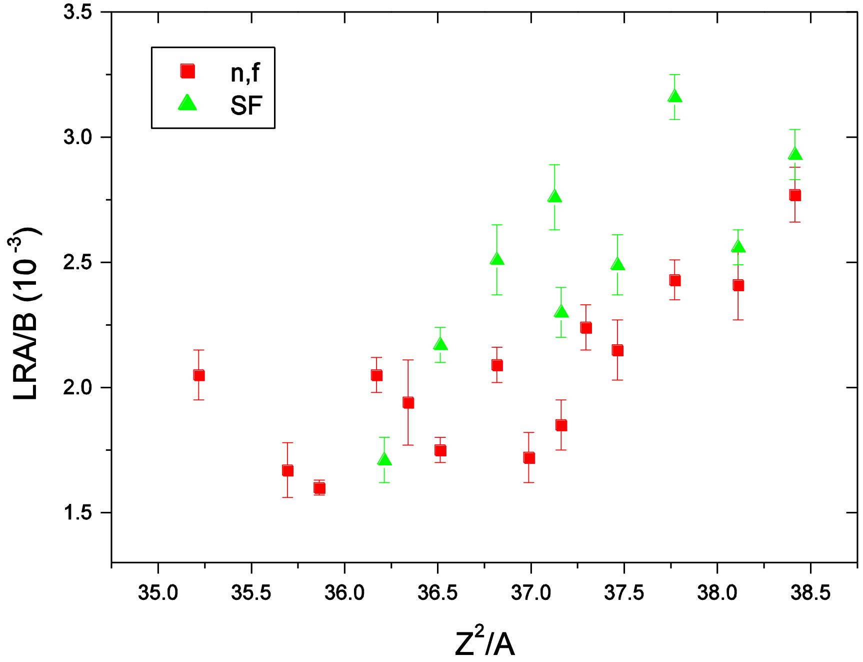
Increases with increasing Z^2/A

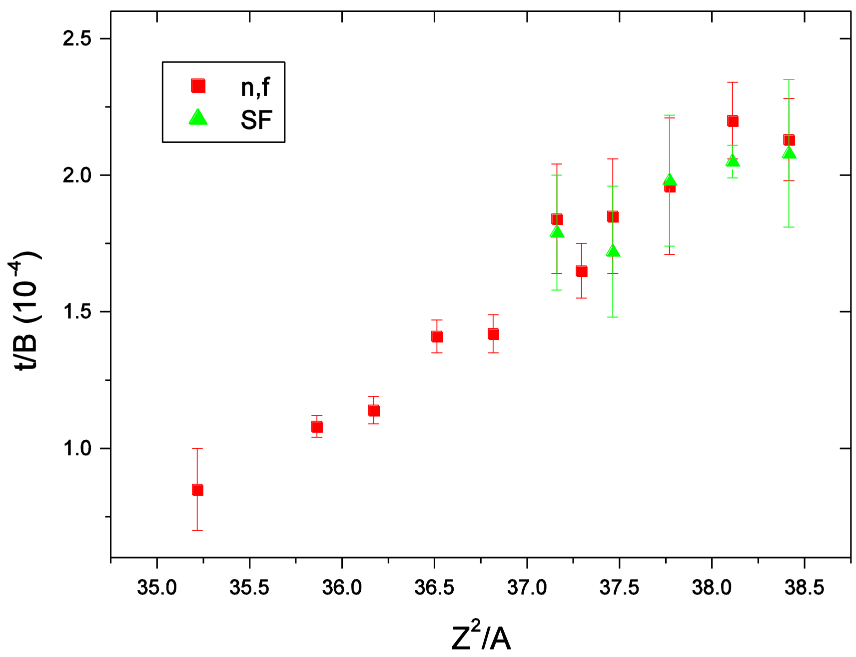
(explained by trajectory calculations)

High Flux Reactor ternary fission

Emission probability: LRA/B and t/B

as a function of the fissility parameter Z^2/A





Increases with increasing Z^2/A

(Z^2/A is a measure of the deformation)

High Flux Reactor — ternary fission

Condition for α emission:
α particle should be present in the fissioning nucleus

Introduction of the factor S_α

= Alpha cluster preformation probability

$$s_\alpha = b\,\frac{\lambda_e}{\lambda_{WKB}}$$

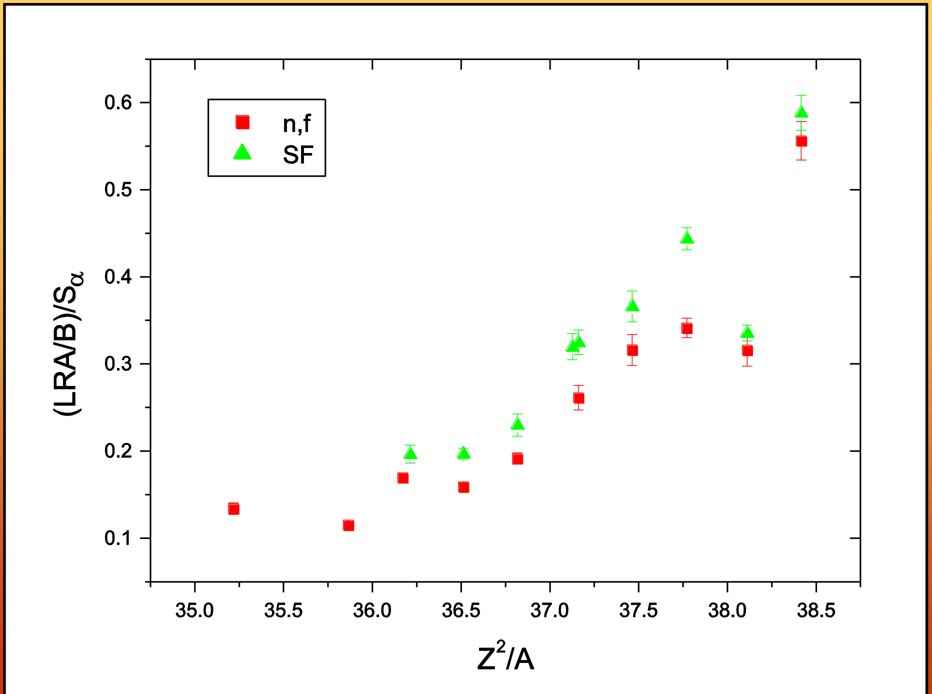
λ_e = experimental alpha decay constant
λ_{WKB} = calculated alpha decay constant

Decreasing value of S_α due to the excitation energy after capture of a neutron

This factor is not involved in the triton emission process

Emission probability: $(LRA/B)/S_\alpha$

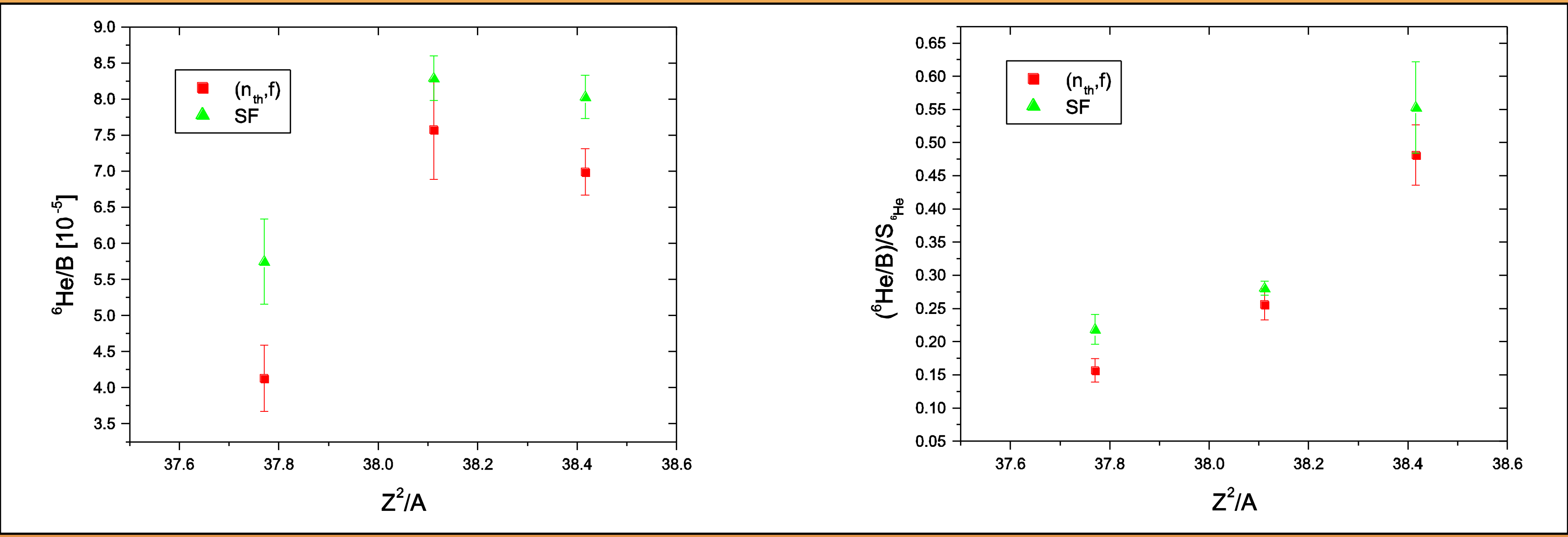
as a function of the fissility parameter Z^2/A



High Flux Reactor ternary fission

Influence of the excitation energy E_{exc}

What about ^{6}He particles?



- higher values SF than (n,f)
- influence factor S(^{6}He)

! ^{6}He particles behave more like α-particles than like tritons

Cross section measurements

IRMM Geel

GELINA $^{245}Cm(n,f)$

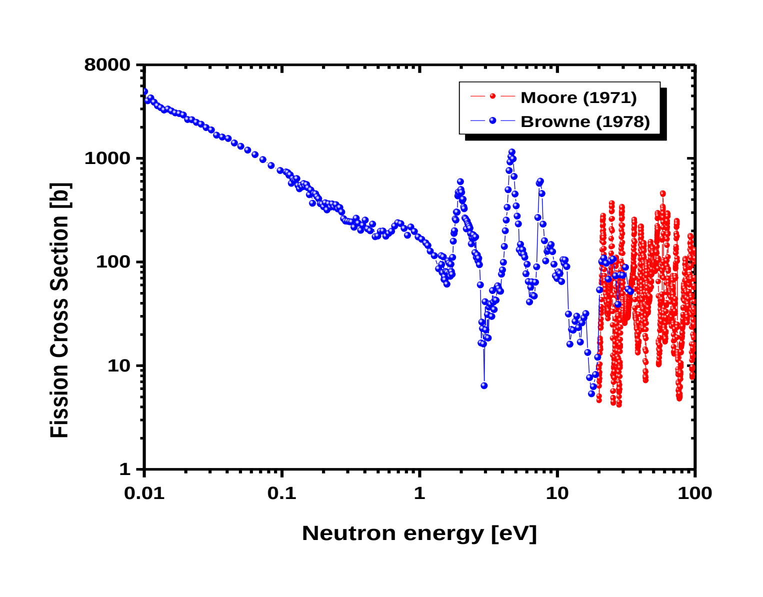
Why do we measure the reaction $^{245}Cm(n,f)$?

Requirement for low-energy neutron induced cross sections for Minor Actinides

- Prediction of heavy actinide concentrations in reactor fuel elements
- Reduction of long-term nuclear waste radiotoxicity by transmutation

Fission cross section for ^{245}Cm: nuclear database

- Thermal fission cross section (strong dispersion) → L. Popescu
- Thermal and resolved resonance region
  - Nice measurement performed by Moore starts at 20eV
    Below 20eV: Browne's measurement with a poor energy resolution

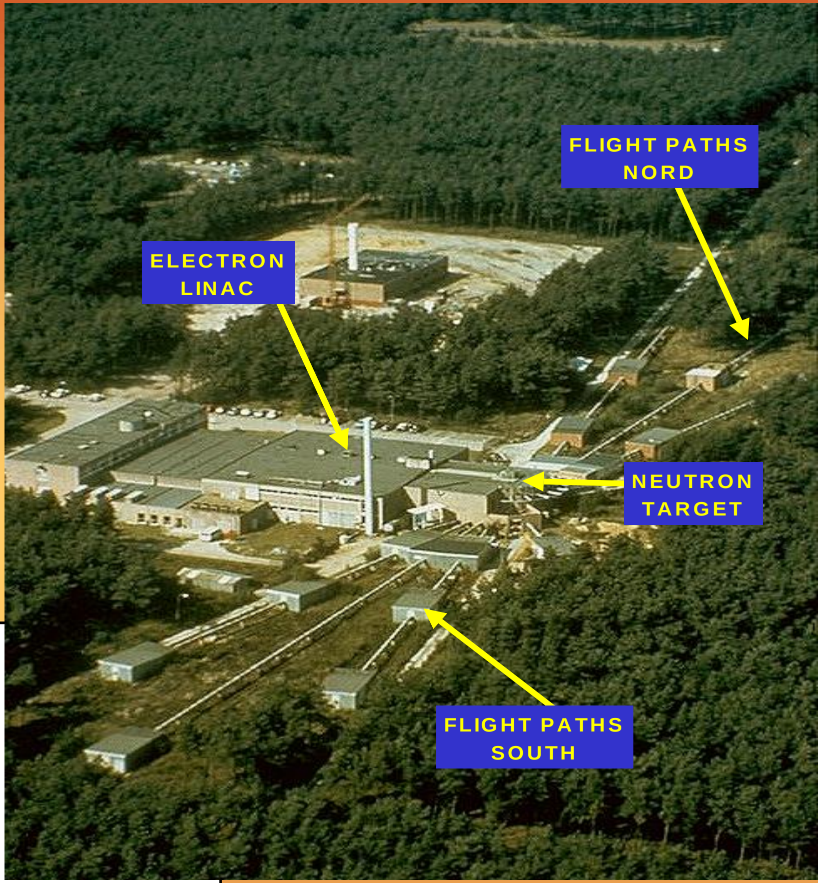


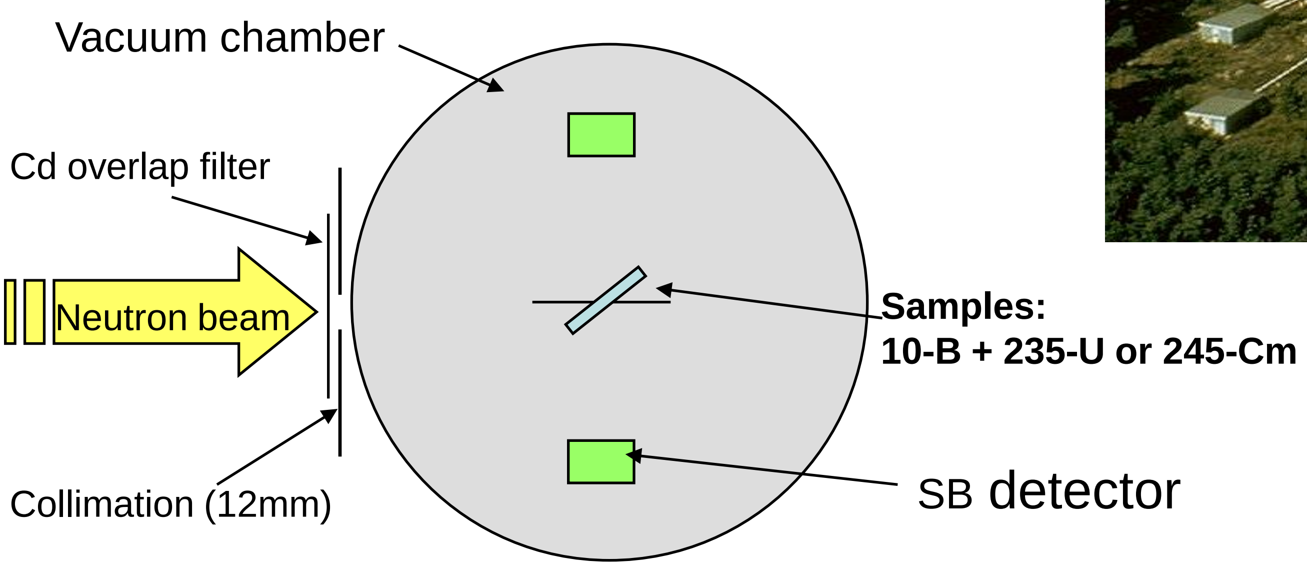
GELINA ^{245}Cm(n,f)

pulsed neutron source:

GELINA (GEel LINear Accelerator) facility

- 9.3m flight path
- 800 Hz repetition rate (resonance region)
- 50 Hz repetition rate (thermal region)



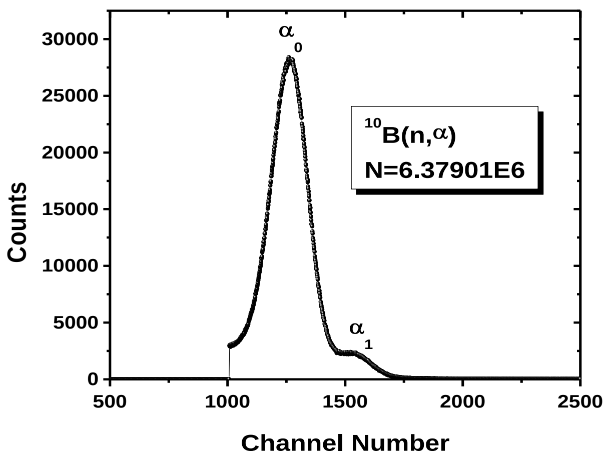


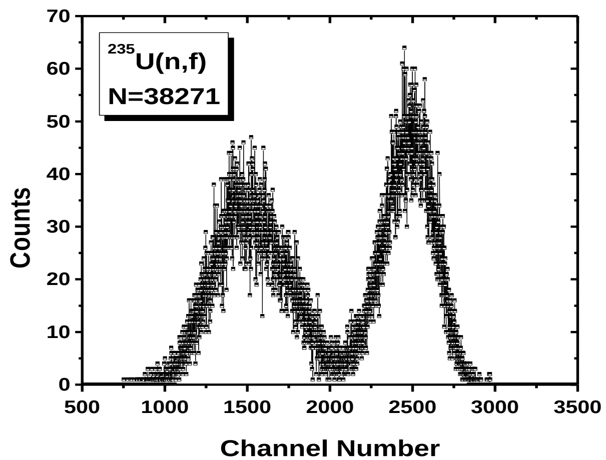
GELINA ^{245}Cm(n,f)

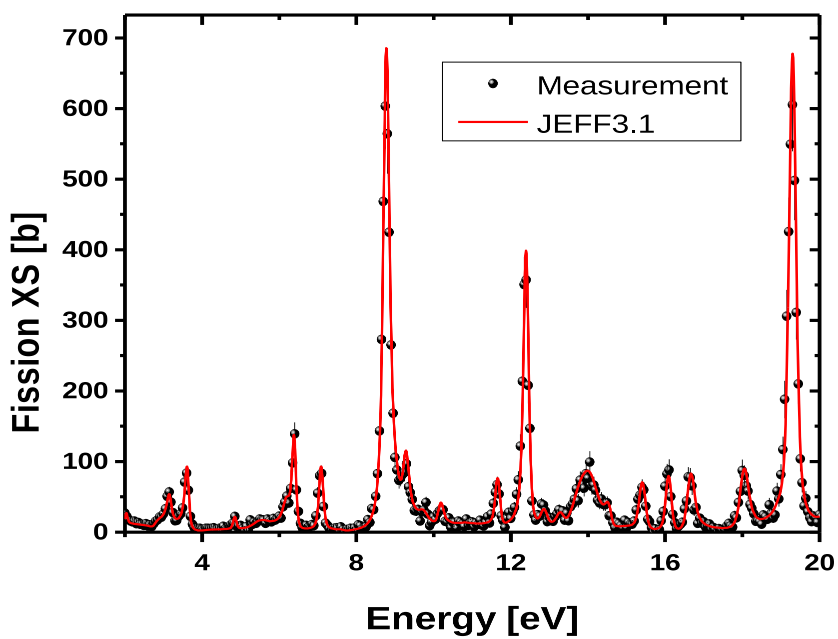
First step: measurement with ^{235}U and ^{10}B samples (800 Hz)

calibration in energy (with the ^{235}U resonances)
determination of the solid angles of the detection

! important to check the good functioning of our detection system: the well-known ^{235}U(n,f) cross section must be well reproduced





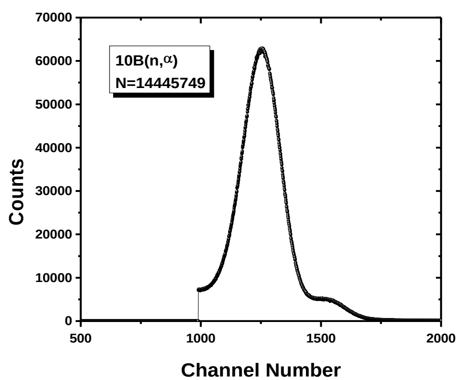


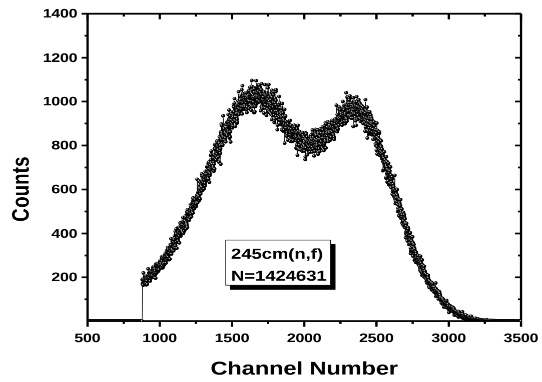
GELINA $^{245}Cm(n,f)$

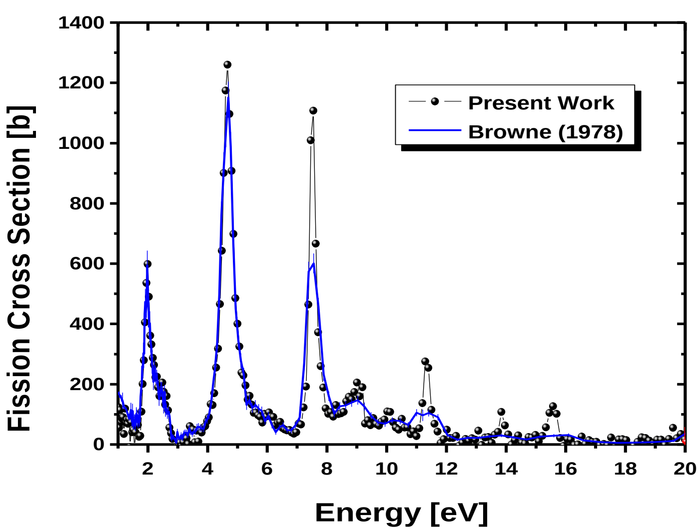
Second step: measurement with ^{245}Cm and ^{10}B samples (800 Hz)

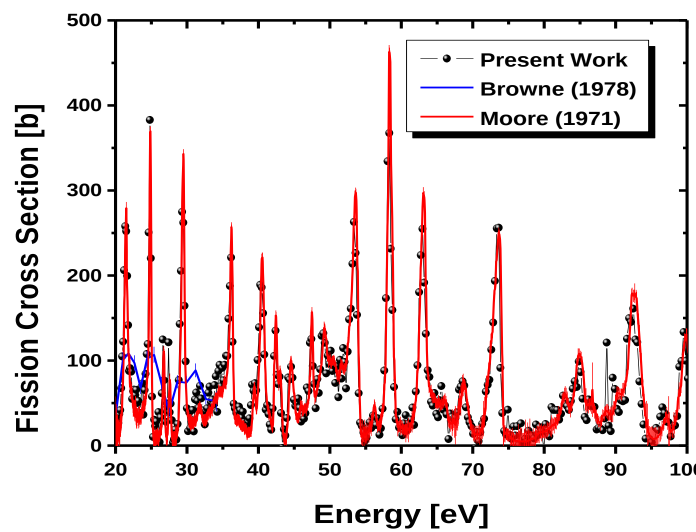
→ determination of the $^{245}Cm(n,f)$ cross section

- Below 20 eV: the energy resolution was improved compared to the Browne's measurement
- Above 20 eV: nice agreement with the Moore's measurement









GELINA $^{245}Cm(n,f)$

Third step: measurement with ^{235}U and ^{10}B samples (50 Hz)

Fourth step: measurement with ^{245}Cm and ^{10}B samples (50 Hz)

- measurements partly done
- to be analyzed
- main goal: determine Westcott g_f factor (measurement of deviation from 1/v)

GELINA $^{41}Ca(n,\alpha)$

Why do we measure the reaction $^{41}Ca(n,\alpha)^{38}Ar$?

astrophysical reasons

important in the quest for the origin of ^{36}S

- earlier measurement at flightpath 8.5m:
  cross section measured from some hundreds eV up to 45 keV
  as well as thermal cross sections

- ongoing measurement on flightpath 30m:
  extend the energy range and improve the energy resolution

Conclusions

neutron induced reaction measurements are important

1 at the High Flux Reactor of the ILL:

for ternary fission measurements

- new results on $^{249}Cf(n,f)$
- enlarge available database
- able to search for systematics

2 at GELINA:

- determination of the $^{245}Cm(n,f)$ cross section
  - preliminary results
  - further measurements to improve statistics and to determine Westcott g_f factor
- determination of $^{41}Ca(n,\alpha)$ cross section